REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
19 March 2012	Final Technical Report	01 January 2008 to 31 December 2012

4. TITLE AND SUBTITLE

Climate change and baleen whale trophic cascades in Greenland

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N000140810361

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Kristin L. Laidre and Mads Peter-Heide-Jorgensen

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Polar Science Center, Applied Physics Laboratory, University of Washington,
1013 NE 40th St. Seattle, WA 98105 USA

8. PERFORMING ORGANIZATION REPORT NUMBER

GC1 A 27572

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
1107 NE 45th Street
Suite 350
Seattle, WA 98105-4631

10. SPONSOR/MONITOR'S ACRONYM(S)

ONR - NOPP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is Unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

We focused on two cetacean species in Disko Bay, West Greenland and asked the following questions: 1) "What is the spatial and temporal overlap between bowhead whales, phytoplankton, and zooplankton after the spring sea ice breakup in April and May?", and 2) "What is the spatial and temporal overlap between humpback whales and capelin in June and July, and 3) on what space and time scales do these two large whales overlap?". Answering these questions enabled us to determine the spatial, temporal, and ecological overlap between these two top predators in West Greenland. This is one of the few high Arctic studies conducted on the multi-species trophic coupling between whales and their prey. The simplicity of the food chains in West Greenland offer unique opportunities to gain insight into predator-prey dynamics also relevant to more complex ecosystems.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
Unclassified					Leslie Harding
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	None	5	**19b. TELEPHONE NUMBER** *(include area code)*
U	U	U			206-543-7048

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

Climate change and baleen whale trophic cascades in Greenland

Kristin L. Laidre
Polar Science Center, Applied Physics Laboratory, University of Washington,
1013 NE 40th St. Seattle, WA 98105 USA
Phone: 206-616-9030, FAX: 206-616-3142, email: klaidre@apl.washington.edu

Mads Peter Heide-Jørgensen
Greenland Institute of Natural Resources, Box 570, Nuuk 3900 Greenland
Phone: + 299 361200, FAX +299 361201, email: mhj@ghsdk.dk

FINAL REPORT Award Number: N000140810361

LONG-TERM GOALS

The primary goals of this study have been to examine and contrast the foraging strategies of two baleen whale species in West Greenland. We used a multidisciplinary approach by combining observations of movements, foraging ecology and phenology collected by satellite and archival telemetry with intensive and localized *in situ* sampling of ocean conditions and prey availability. These baseline trophic relationships are quantified using spatial movement and bioenergetic models. We have accomplished our long-term goals and have produced 5 primary peer-reviewed manuscripts (published or In Press) between 2010-2012. At least two more manuscripts are "In Review" and one is "In preparation".

OBJECTIVES

We focused on two cetacean species in Disko Bay, West Greenland and asked the following questions: 1) "What is the spatial and temporal overlap between bowhead whales, phytoplankton, and zooplankton after the spring sea ice breakup in April and May?", and 2) "What is the spatial and temporal overlap between humpback whales and capelin in June and July, and 3) on what space and time scales do these two large whales overlap?". Answering these questions enabled us to determine the spatial, temporal, and ecological overlap between these two top predators in West Greenland. This is one of the few high Arctic studies conducted on the multi-species trophic coupling between whales and their prey. The simplicity of the food chains in West Greenland offer unique opportunities to gain insight into predator-prey dynamics also relevant to more complex ecosystems.

APPROACH

The study focused on the foraging ecology of bowhead whales in late-spring just after sea ice break-up. Annual sea ice conditions, including ice concentrations, timing of break-up and locations of the ice edge, were assessed using remotely sensed imagery (MODIS, SMMR/SSMI) (See Laidre and Heide-Jørgensen 2004). Satellite-linked tags are deployed on bowhead whales to determine small-scale movements in Disko Bay, and the timing of departure and movements during spring and summer. These tags were location-only transmitters as well as binned-dive data transmitters (SPOT5, MK10 and SPLASH tags, Wildlife Computers) with a longevity of 6-12 months. Bowhead whales were also instrumented with high resolution retrievable GPS-based Argos data collection transmitters. The

calculation of GPS positions allows for location accuracy of +/- 55 meters (95%) where the whale was surfacing. Collected data included dive depth, duration of dives, and time-at-depth sampled in 1 hour intervals. These data are coupled to epibenthic zooplankton data to quantify the spatial and temporal variability in Disko Bay. Near-bottom zooplankton concentrations were investigated at 25 stations where bowhead whales feed. Data were collected with an epibenthic sled and WP2 plankton net, and the zooplankton biomass was determined by simple measurements of volumetric displacement. Further quantification of epibenthic zooplankton abundance was conducted by use of a 200 KHz submersible split-beam echo sounder, which estimates vertical gradients in zooplankton concentrations as well as patchiness between stations.

The portion of the study focused on the foraging ecology of humpback whales utilized satellite telemetry deployed on whales in spring when they arrive en route from the Caribbean to their feeding areas. The focus as on obtaining a large sample size of tagged whales so that spatial movement patterns and focal areas can be robustly calculated. Movement data were used to describe movement patterns and use of focal areas along the coast using probabilistic spatial techniques, including the time individuals spend feeding in each site and the phenology of the use of the focal areas. These data were related to long-term physical and biological monitoring program in Nuuk Fjord and on the coast of West Greenland, where long-term fishery data are collected to quantify seasonal and inter-annual variations in the biological and geophysical properties of the marine ecosystem.

WORK COMPLETED

Field work. All field work was completed between 2008 and 2010 and is detailed in annual reports to ONR. We focused on analysis in 2011, operating under a no-cost extention until December 31, 2011.

RESULTS

We highlight our accomplishments across all years of the project by describing the five peer-reviewed publications that have been products between 2010 and 2012. Our most recent publication is In Press (2012) by Laidre and Heide-Jørgensen in the *ICES Journal of Marine Science* special issue on Arctic and sub-Arctic ecosystems. This paper examined movements of bowhead whales and humpback whales in Disko Bay using satellite telemetry. We analyzed data on movements, habitat use, and phenology and compared results between species, using n=29 bowhead whales and n=44 humpback whales during the transition from sea ice breakup to open water. We identified significantly different habitat use patterns for the two species in Disko Bay, as well as significant trends in later departure date from Disko Bay for bowhead whales (~ 15 days later, $p<0.001$) between two periods 2001-2006 and 2008-2010.

The second publication is Heide-Jørgensen et al. (2011) in *Biology Letters*. This manuscript presented the first observations of distribution overlap of bowhead whales from the two oceans in the Northwest Passage, demonstrating this route is already connecting whales from two populations that have been assumed to be separated by sea ice. Previous satellite tracking has demonstrated that bowhead whales from West Greenland and Alaska enter the ice-infested channels of the Canadian High Arctic during summer (tracking in 2002 and 2003). However in August 2010, two bowhead whales (one tagged in Disko Bay, West Greenland in this study) and one tagged in Alaska entered the Northwest Passage from opposite directions and spent approximately 10 days in the same area, documenting overlap between the two populations.

The third publication is Heide-Jørgensen et al. (2010) in *Endangered Species Research*. Data from skin biopsy samples from 806 bowhead whales collected between 1995 and 2010 at four locations in Nunavut, Canada, (Foxe Basin, Pelly Bay, Repulse Bay and Cumberland Sound) and at

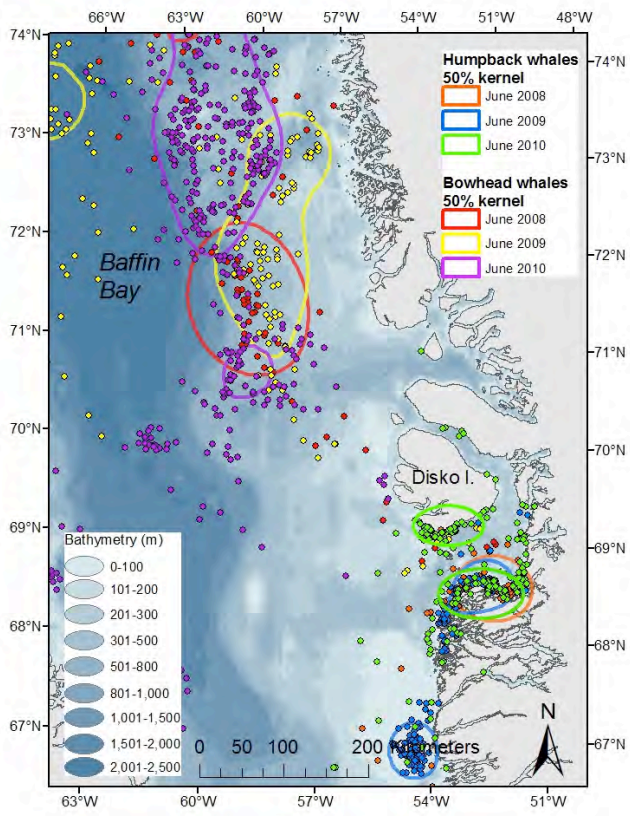
one locality in West Greenland (Disko Bay) were used for determination of sex and sexual segregation of bowhead whales in the Baffin Bay stock. This included genetic samples collected during this NOPP program from 2008-2010 (n=61, 69, and 89, respectively). There was a significant dominance of females in the Disko Bay samples (78%) whereas the sex ratio in aggregations at other locations in Nunavut was not significantly different from 50:50. On a broader scale, Baffin Bay is more widely used by adult males and resting or pregnant females from Disko Bat while Prince Regent, Gulf of Boothia, Foxe Basin and north-western Hudson Bay animals are all areas used by nursing females, calves and sub-adults.

The fourth publication is Wiig et al. (2011) in *Endangered Species Research*. In this paper, we used multi-locus genotype and sex to identify individual bowhead whales from 710 samples collected between 1995 and 2010 at 4 localities in eastern Canada (Foxe Basin, Pelly Bay, Repulse Bay, and Cumberland Sound) and at 1 locality in West Greenland (Disko Bay). In total, 29 recaptures of the same individuals were identified between years, of which 26 individuals were recaptured within the same locality. The remaining 3 were recaptured between sampling localities, from 2 putative International Whaling Commission (IWC) stocks: the Hudson Bay−Foxe Basin stock and the Baffin Bay−Davis Strait stock. These recaptures agree with satellite tracking results that demonstrate movement between IWC stocks and question whether these stocks are true biological entities. The intervals between capture and recapture of females in Disko Bay ranged from 1 to 8 yr. The observed number of multi-year recaptures compared to the expected numbers of recaptures did not indicate any clear cyclicity in the use of Disko Bay consistent with the notion that the migration pattern of females to this area might be tied to their reproductive cycles. A mark−recapture estimate of whales identified in 2010 compared to all dentifications between 2000 and 2009 resulted in an estimate of 1410 bowhead whales (SE = 320, 95% CI: 783−2038) constituting the spring aggregation in Disko Bay. The estimate for the female portion of the aggregation was 999 individuals (SE = 231, 95% CI: 546−1452).

In the fifth publication was Laidre et al. (2010) in *Marine Ecology Progress Series*. This study This study combined data on large whale sightings, including humpback whales (a focal species in this study) from large scale visual aerial and ship-based surveys with synoptic acoustic sampling of krill (*Meganyctiphanes norvegica* and *Thysanoessa sp.*) abundance to examine the spatial relationships between whales and their prey. Standard regression models (GAM) were developed to identify important explanatory variables relating the presence, absence, and density of large whales to the physical and biological environment and survey platforms. We identified three focal areas for large baleen whales. Habitat models indicated the most important parameter in predicting large baleen whale presence was integrated krill abundance although a high degree of spatio-temporal synchrony in observations is necessary for quantifying the relationship.

We also have two manuscripts in review: One manuscript on genetics of bowhead whales (Bachmann et al. In Prep) examining genetic differentiation between Baffin Bay-Davis Strait and Hudson Bay-Foxe Basin stocks of bowhead whales using mitochondrial control region sequences and one manuscript on zooplankton densities in Disko Bay (Andersen et al.). Finally, we continue developing bioenergetic predation models based on the dive data collected from GPS tags. We are in the analysis and writing phase of another manuscript that identifies U- and V-shaped feeding dives and measures the proportion of time spent on the bottom of each time together with velocity (Heide-Jørgensen et al. In Prep). Furthermore, we continue analysis of genetic and satellite-telemetry movement and expect several more papers to come out of this study in the future.

Figure 1. Map from Laidre and Heide-Jørgensen et al. (2012) showing focal areas for bowhead whales and humpback whales tagged in this study in June in West Greenland, 2008-2010.



IMPACT/APPLICATIONS

1. A new perspective on the interaction between sub-Arctic and Arctic baleen whales in West Greenland. Few studies have been conducted on the trophic coupling between whales and their prey, given the dynamic nature of the marine environment and the difficulty in observing or quantifying feeding behavior. By instrumenting individual bowhead and humpback whales in a defined region of West Greenland, we have been able to examine the movements and space use patterns of each species, together with how the two species overlap in space and time and compete for resources.

Potential future impact for Science and/or Systems Applications

2. New techniques for ecological studies of large whales using telemetry. Our study developed technical and methodological advances which are of broad interest for applications in other regions for whale tagging. We have developed a retrievable archival instrument that can be reliably deployed on a large whale and retrieved up to one month later, providing high resolution GPS location data together with dive data measured on a one-second temporal scale. Furthermore, design and deployment of satellite transmitters for large whales is continually being refined based on field efforts during this project to improve attachment. Our technology enabled tracking of 2 baleen whales for >14 months.

3. New bioenergetic models for bowhead whales. Our study develops new bioenergetic models for bowhead whales which can be previously compared to that reported in Laidre et al. (2007) and other studies. Archival dive data are being summarized and used together characterize dives and determine

the proportion of whale dives that are feeding dives (i.e. U-shaped dives reaching the bottom) and how much time whales spend at different depths. Combining this information, with data on the amount of water filtered by a whale and known area use and temporal extent of occurrence will improve bioenergetic prediction of the food consumption and competition.

RELATED PROJECTS

None.

PUBLICATIONS

Laidre, K. L., and M. P. Heide-Jørgensen. 2012. Springtime partitioning of Disko Bay, West Greenland by Arctic and sub-Arctic baleen whales. ICES Journal of Marine Science. [refereed, in Press].

Heide-Jørgensen M. P., K.L. Laidre, L. T. Quakenbush, and J. Citta. 2011. Northwest Passage opens for bowhead whales. Biology Letters. doi:10.1098/rsbl.2011.0731. [published, refereed]

Wiig, Ø, Bachmann, L., Heide-Jørgensen, M.P., C. Lindquist, Laidre, K.L., Postma, L, Dueck, L. Palsbøll, P, and L. Bachmann. 2011. Recaptures of genotyped bowhead whales (*Balaena mysticetus*) in Eastern Canada and West Greenland. Endangered Species Research 14: 235-242. [published, refereed]

Heide-Jørgensen, M.P., K. L. Laidre, Ø. Wiig, L. Postma, L. Dueck, L. Bachmann. 2010. Large scale sexual segregation of bowhead whales. Endangered Species Research 13:73-78. [published, refereed]

Laidre, K. L., M. P. Heide-Jørgensen, P. Heagerty, A. Cossio, B. Bergstrom, and M. Simon. 2010. Spatial associations between large baleen whales and their prey in West Greenland. Marine Ecology Progress Series 402:269-284. [published, refereed]

Andersen O. G. N., K. Laidre, and M. P. Heide-Jørgensen. In Review. Benthopelagic fauna on a bowhead whale foraging ground in Disko Bay, West Greenland. Marine Biology Research [In review].

Bachmann, L., Wiig, Ø., Postma, L., Dueck L., Heide-Jørgensen, M.P., Laidre, K.L. and Palsbøll, P. 2010. Genetic diversity in Eastern Canada and Western Greenland bowhead whales. Endangered Species Research [In review].

AWARDS

Laidre K. L. Spoken Presentation: Climate change and baleen whale trophic cascades in Greenland Award: Honorable mention for Best Spoken Presentation by Young Scientist. Ecosystem Studies of Sub-Arctic Seas (ESSAS) Open Science Meeting, Seattle, WA May 22-26, 2011, Comparative Studies of Polar and Sub-Polar Ecosystems.